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Mizutani et al.

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(54) **SPARK PLUG**

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H01T 13/32 (2006.01)
H01T 13/52 (2006.01)

(52) **U.S. Cl.**
CPC ***H01T 13/32*** (2013.01); ***H01T 13/20*** (2013.01); ***H01T 13/52*** (2013.01)

(58) **Field of Classification Search**
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USPC 313/118, 135, 137, 141–145
See application file for complete search history.

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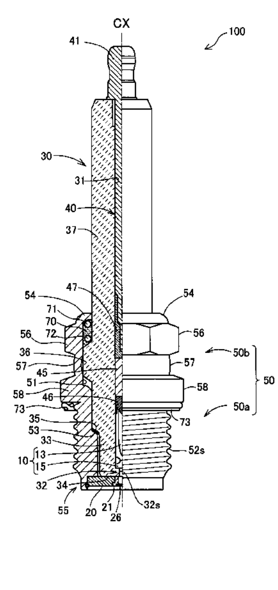
(57) **ABSTRACT**

An ignition plug having a center electrode, a grounding electrode, an insulator, and a metal shell. The center electrode is held by the insulator, and the insulator is held by metal shell. A cavity is formed between the grounding electrode and the center electrode. The grounding electrode is joined to the inner wall surface of the metal shell via a melting portion. In the melting portion, in a predetermined cutting surface MS including a melting deepest point DP and a central axis CX, a percentage ratio MDD of a melting depth MD of the melting portion with respect to a thickness of the grounding electrode is 5% or more, and an area Sm of a portion included in an outer circumferential side of the metal shell is 10% or more of the entire area S.

13 Claims, 10 Drawing Sheets



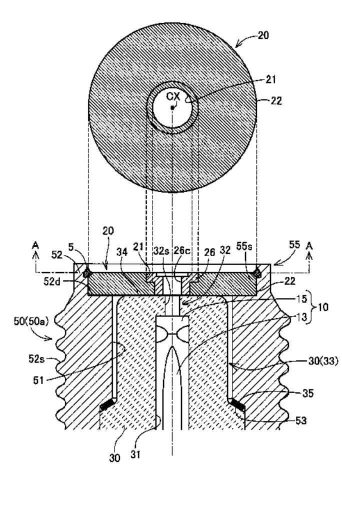
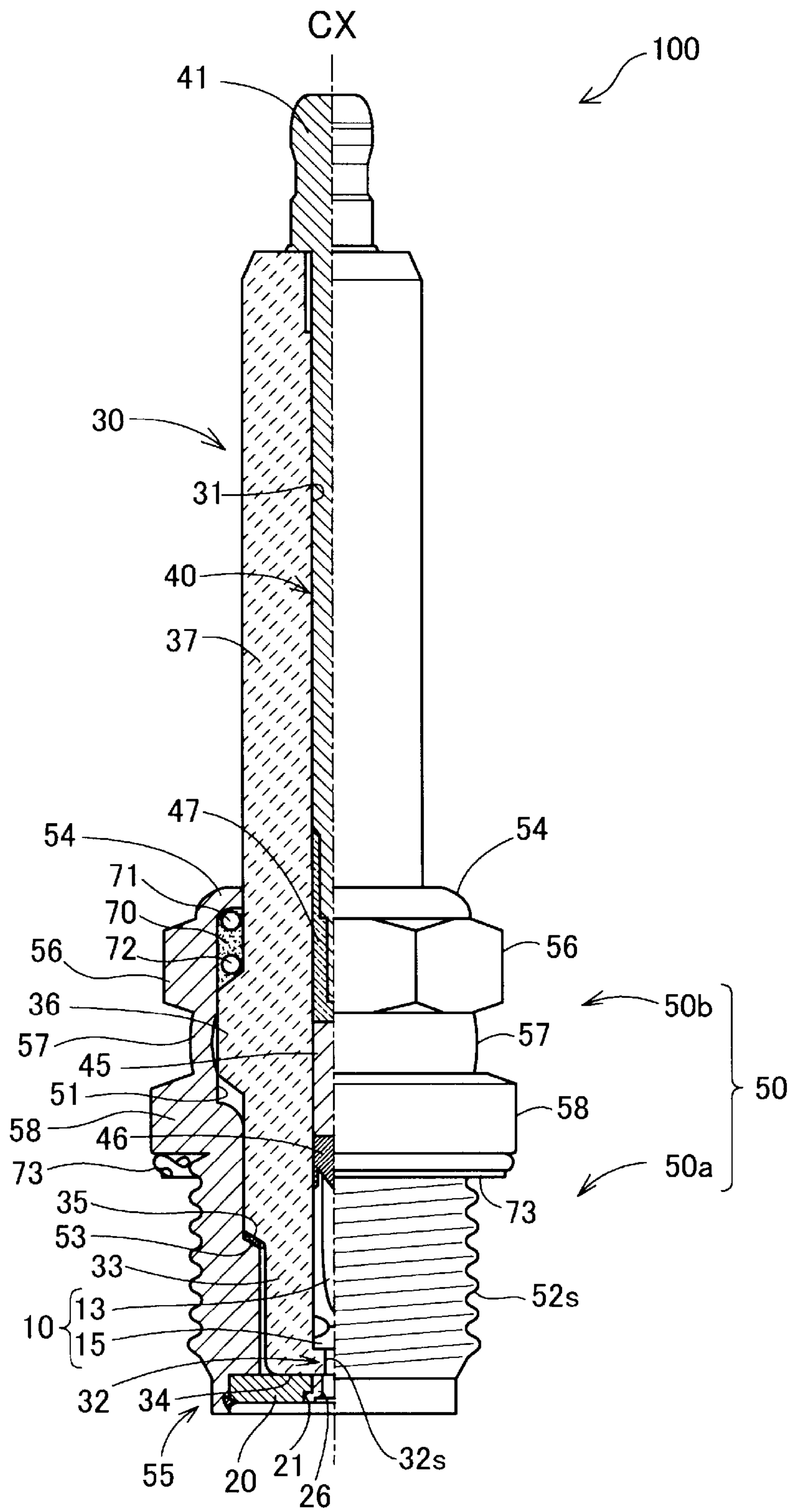


FIG. 1


CX
100
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30
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70
72
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36
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45
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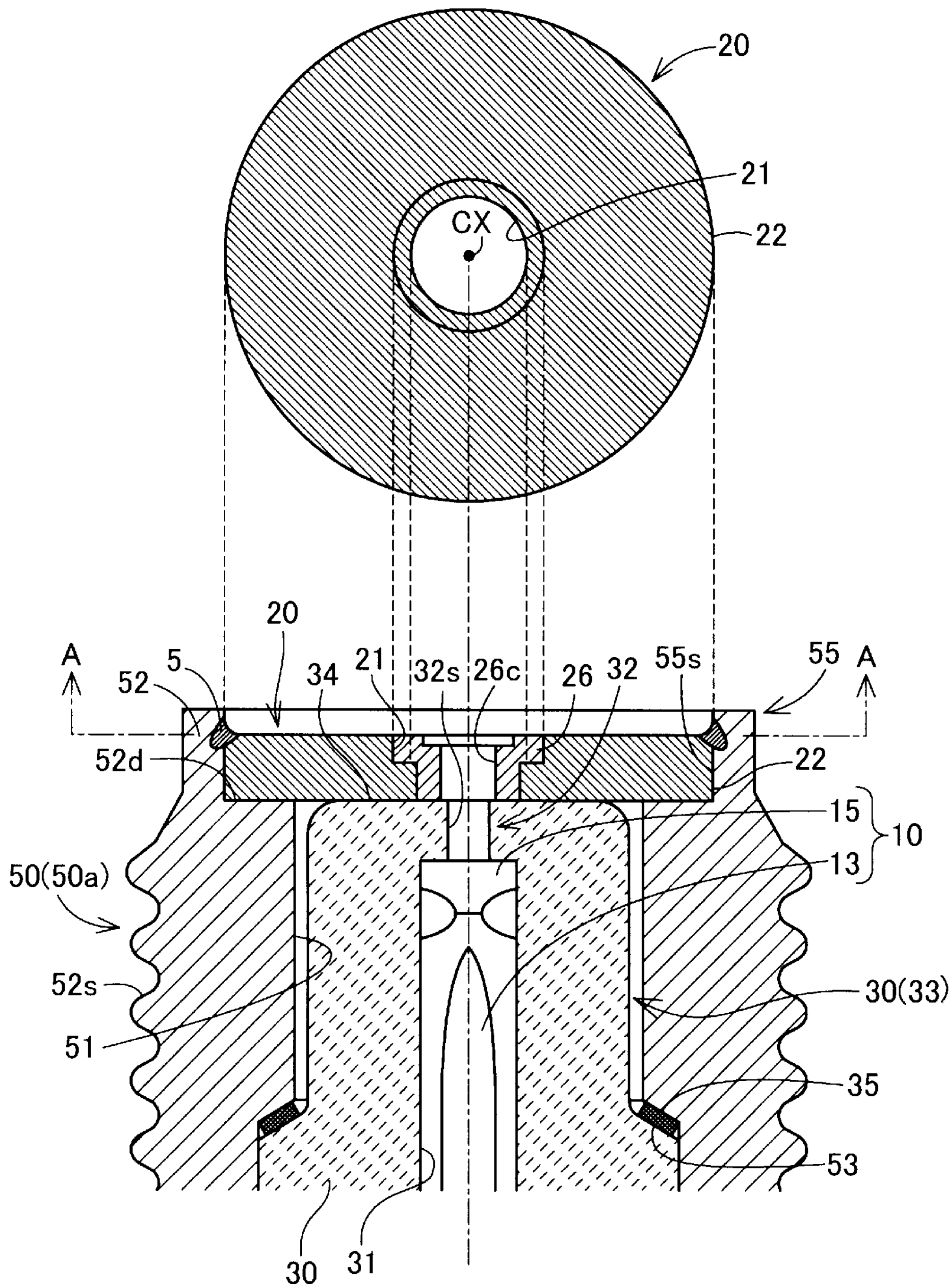
58
46
73
35
53
33
13
10
15
32
34
55
20
21
26
32s
52s
50b
50
50a

FIG. 2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CX
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A
5
52
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21
32s
26c
26
32
55s
55
A
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22
15
10
13
50(50a)
52s
30(33)
51
35
53
30
31

FIG. 3

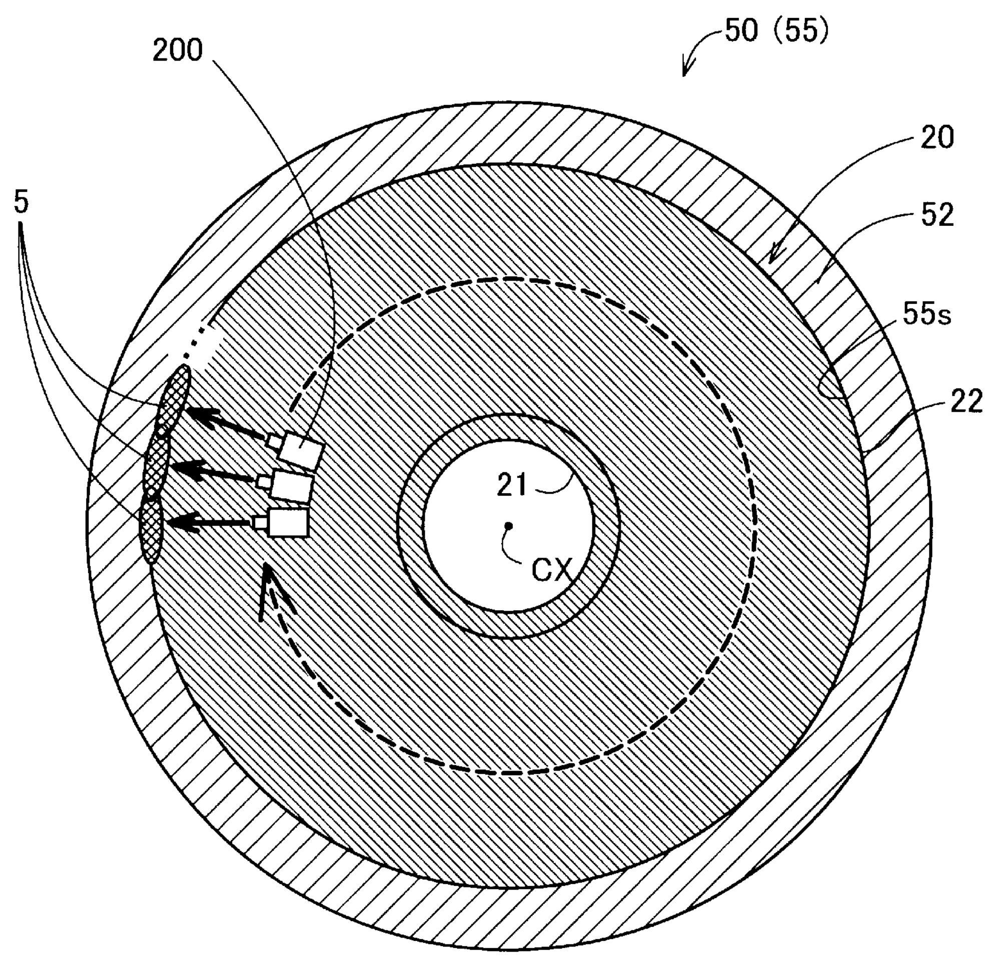


FIG. 4

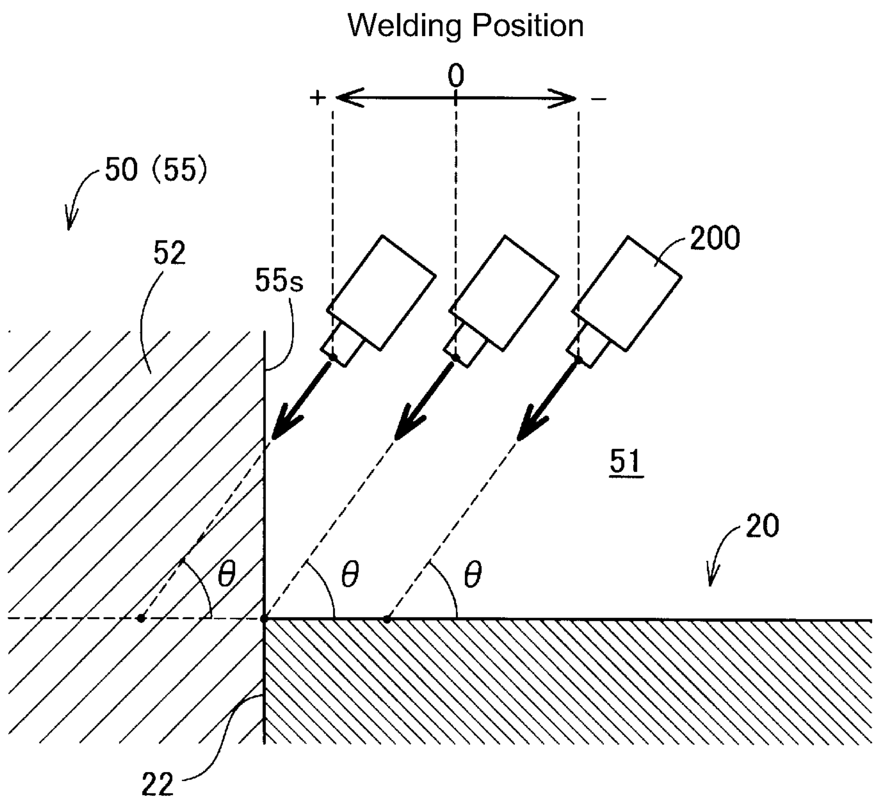


FIG. 5

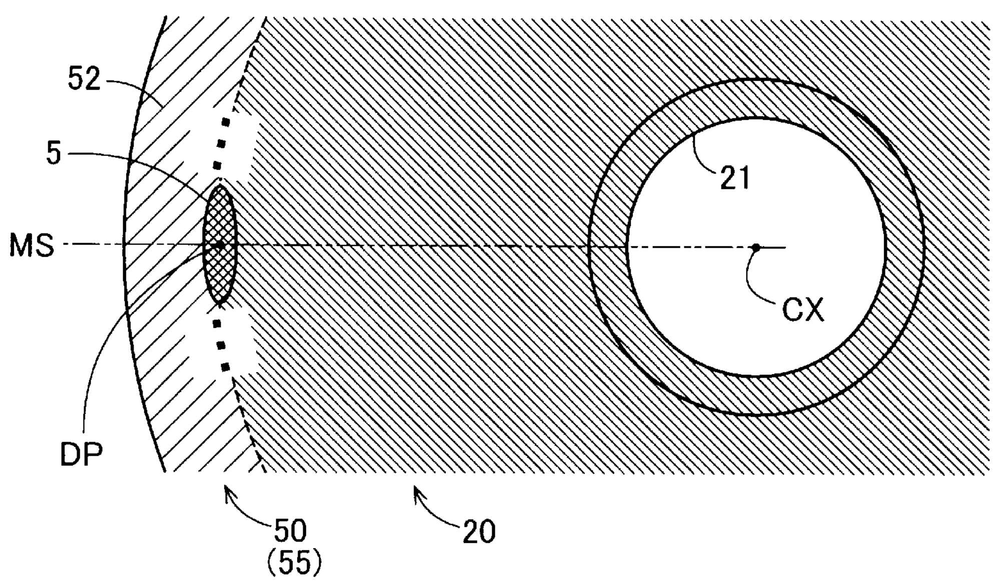
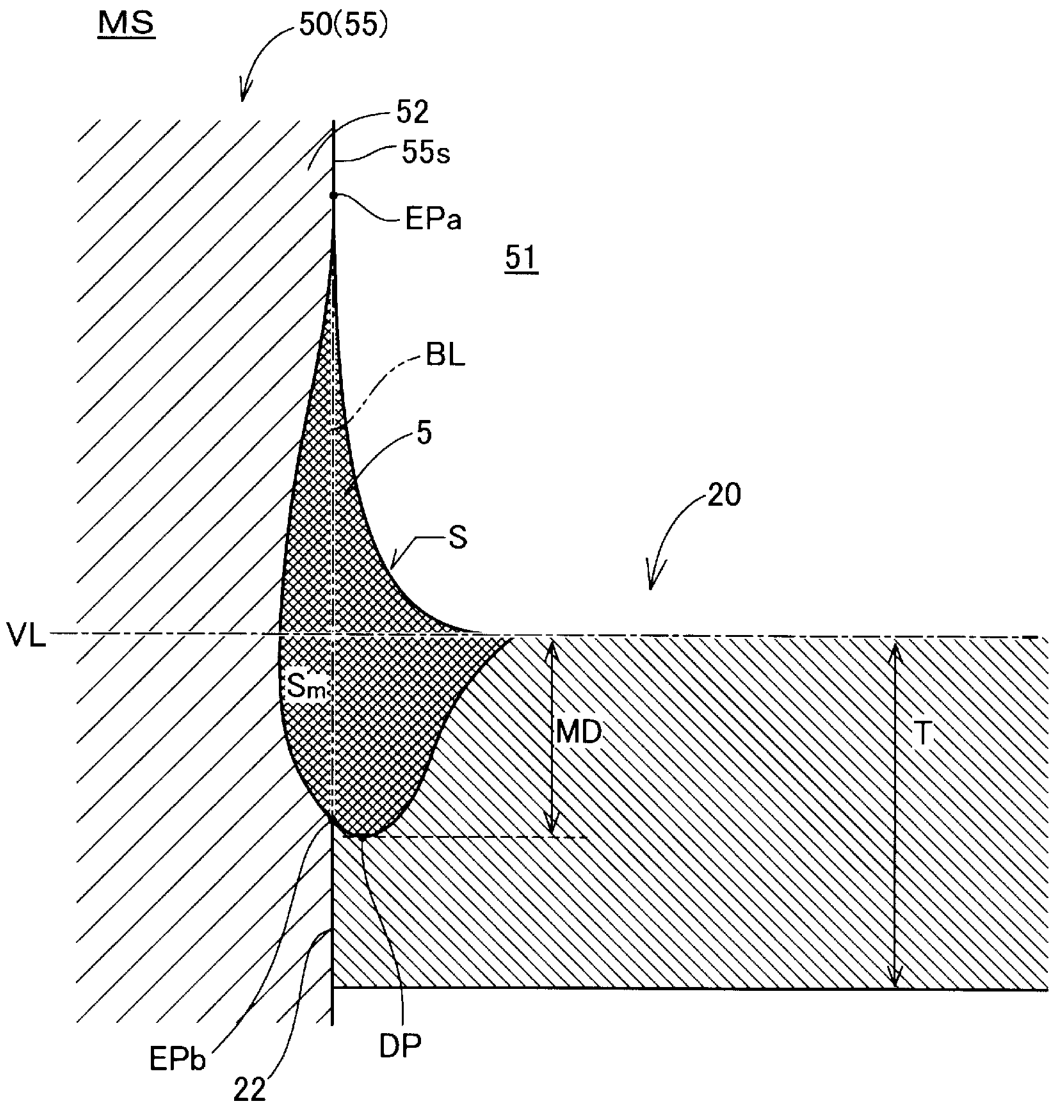


FIG. 6



Melting Depth Ratio

$MDD = (MD / T) \times 100 \geqq 5\%$

Melting Area Ratio

$MSD = (Sm / S) \times 100 \geqq 10\%$

FIG. 7

Sample No.	Welding Condition		Result		
	Welding Position	Laser Output	Melting Area Ratio MSD	Melting Depth (MD) (Melting Depth Ratio MDD)	Welding Strength
S01	−0.04mm	102W	22%	0.36mm (18%)	3600N
S02	−0.04mm	162W	20%	0.76mm (38%)	3900N
S03	−0.02mm	122W	29%	0.54mm (27%)	3900N
S04	−0.02mm	142W	58%	0.72mm (36%)	4100N
S05	0.03mm	132W	40%	0.62mm (31%)	4000N
S06	0.08mm	122W	20%	0.51mm (25.5%)	3900N
S07	0.08mm	142W	54%	0.77mm (38.5%)	4100N
S08	0.10mm	102W	36%	0.30mm (15%)	3700N
S09	−0.04mm	72W	8%	0.12mm (6%)	2700N
S10	0.03mm	82W	15%	0.15mm (7.5%)	3200N
S11	0.10mm	72W	13%	0.07mm (3.5%)	2900N
S12	−0.05mm	180W	25%	0.9mm (45%)	4500N
S13	0.00mm	184W	26%	1.06mm (53%)	4700N
S14	0.04mm	187W	40%	0.98mm (49%)	4600N
S15	−0.05mm	188W	37%	0.98mm (49%)	4600N
S16	0.05mm	188W	56%	1.04mm (52%)	4700N

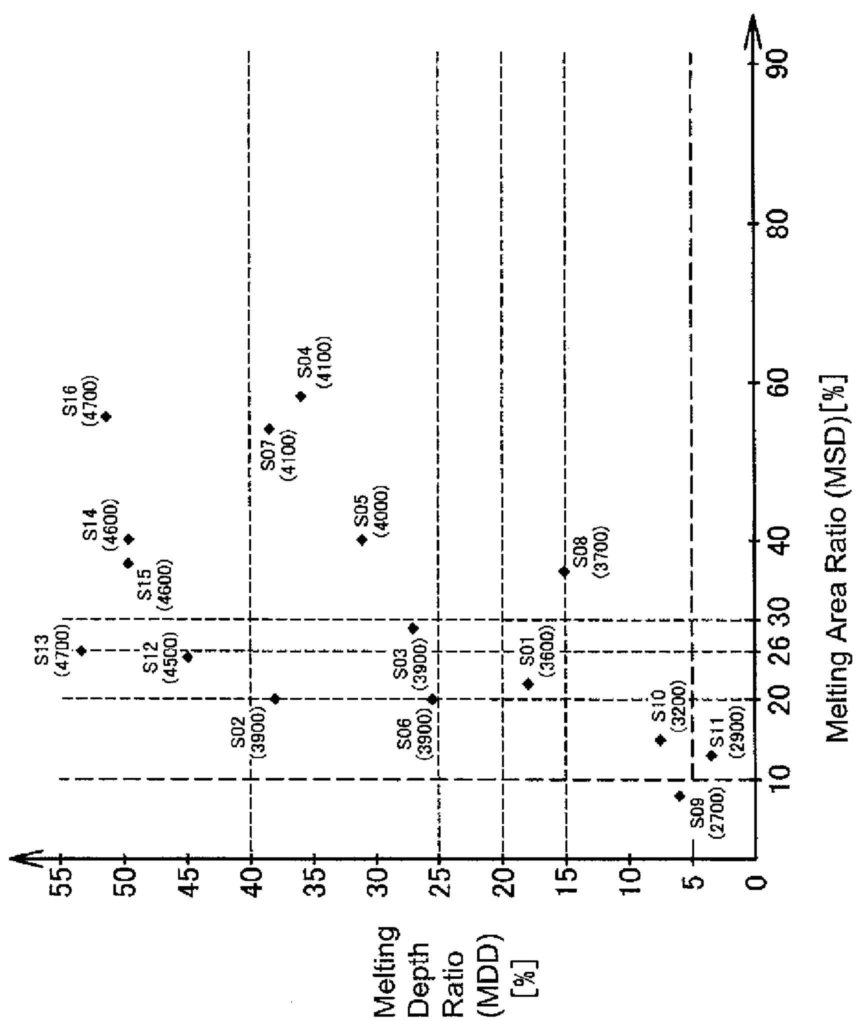

Melting Depth Ratio (MDD) [%]
Melting Area Ratio (MSD) [%]
S01 (3600)
S02 (3900)
S03 (3900)
S04 (4100)
S05 (4000)
S06 (3900)
S07 (4100)
S08 (3700)
S09 (2700)
S10 (3200)
S11 (2900)
S12 (4500)
S13 (4700)
S14 (4600)
S15 (4600)
S16 (4700)

FIG. 8

FIG. 9

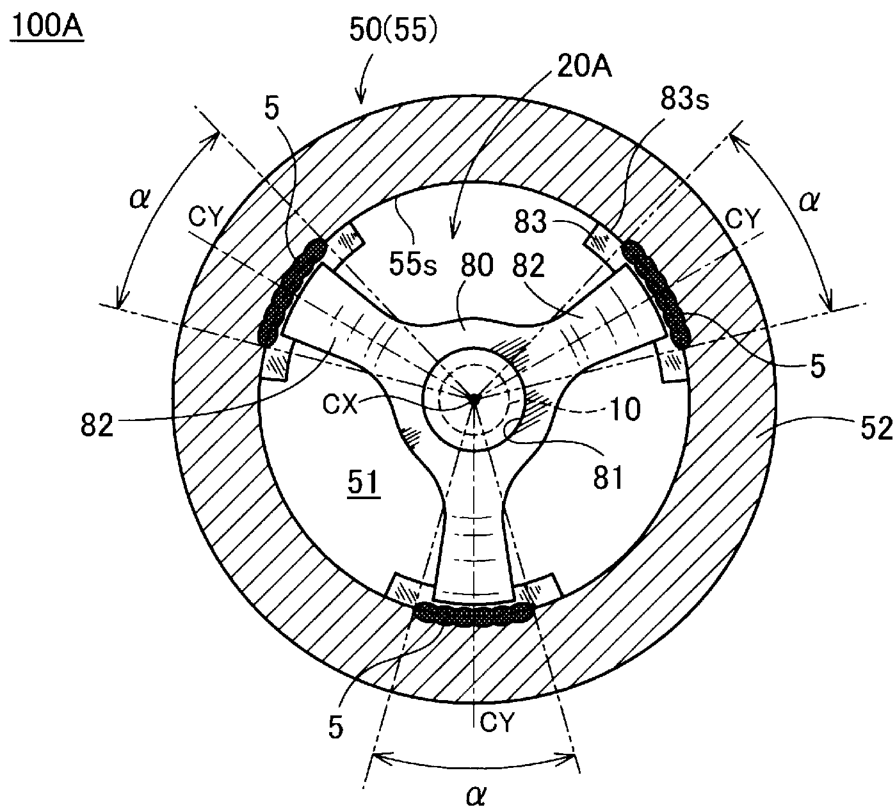
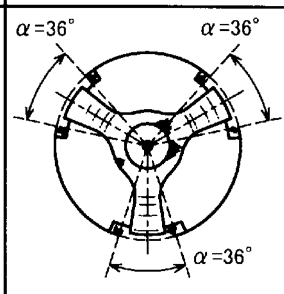
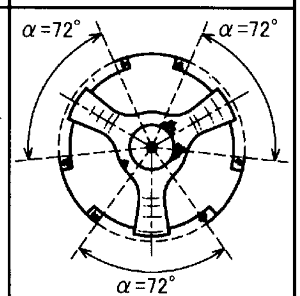


FIG. 10

Sample No.	S20	S21
Melting Portion Formation Range		
	Range of Central Angle a=36° of Grounding Electrode	Range of Central Angle a=72° of Grounding Electrode
Welding Frequency	30回	60回
Melting Depth (MD) (Welding Depth Ratio MDD)	0.62mm (31%)	0.62mm (31%)
Melting Area Ratio (MSD)	40%	40%
Welding Strength	2700N	3900N

SPARK PLUG

FIELD OF THE INVENTION

The present invention relates to a spark plug.

BACKGROUND OF THE INVENTION

A spark plug includes a center electrode and a grounding electrode. The center electrode is held by an insulator, and the grounding electrode is fixed to a metal shell which accommodates the insulator. A spark gap, which is a gap for generating spark discharge, is formed between the center electrode and the grounding electrode. The spark plug generates the spark discharge in the spark gap, and thus, ignites gas supplied into a combustion engine of an internal combustion engine.

Like the spark plug, a plasma jet ignition plug is known (for example, refer to JP-A-2009-224345). In the plasma jet ignition plug, the grounding electrode is joined to an inner circumferential surface of the metal shell and is integrated with the metal shell, the spark gap between the center electrode and the grounding electrode is surrounded by the insulator, and a discharge space having a small volume, referred to as a cavity, is formed.

In the plasma jet ignition plug, as described above, the grounding electrode is joined to the inner wall surface of the metal shell. In the plasma jet ignition plug, the joining property of the grounding electrode where it is secured to the metal shell, preferably, at a high level.

In the technology of JP-A-2009-224345, a tip portion of the insulator is strongly pressed to the grounding electrode, and thus, an object thereof is to prevent the insulator from being damaged. Accordingly, in JP-A-2009-224345, a special consideration is not made for the securing of the joining property of the grounding electrode with respect to the metal shell. Not only in the plasma jet ignition plug disclosed in JP-A-2009-224345, but also in a spark plug having a type in which a grounding electrode is welded to an inner wall surface of a metal shell as described in U.S. Pat. No. 6,064,144, there is still room for the improvement of the joining property of the grounding electrode with respect to the metal shell.

The present invention is made to solve the above-described problems, and can be realized according to the following aspects.

SUMMARY OF THE INVENTION

[1] According to an aspect of the present invention, there is provided a spark plug. The spark plug includes a shaft-shaped center electrode. A tubular insulator accommodates at least a rear end-side portion of the center electrode in an inner portion of the insulator. A grounding electrode is disposed to have a gap between a tip portion of the center electrode and the grounding electrode. A tubular metal shell includes a through-hole in which the insulator is accommodated. The grounding electrode may be fixed to an inner wall surface of the through-hole of the metal shell. The grounding electrode may be fixed to the metal shell via a melting portion in which the grounding electrode and the metal shell are melted to each other. In a cross section including a bottom portion of the melting portion, which is the rearmost end-side portion in the melting portion, and a central axis of the through-hole, in the melting portion, a melting depth, which is a distance in a central axis direction of the through-hole between a bottom portion of the melting portion and a virtual straight line including an outline of a tip-side surface of the grounding electrode, may be 5% or more of a thickness of the grounding electrode in the central axis direction. An area of the shell-side portion, which is positioned at an outer circumferential side of the metal shell from a virtual straight line connecting endpoints of the inner wall surface of the metal shell which are positioned at a tip side and a rear end side of the melting portion in the central axis direction, may be 10% or more of the entire area of the melting portion. According to the spark plug of this aspect, joining property between the grounding electrode and the metal shell is secured.

[2] In the melting portion of the spark plug according to another aspect of the present invention, there is provided, in the cross section, the melting depth may be 15% or more of the thickness of the grounding electrode in the central axis direction, and the area of the shell-side portion may be 20% or more of the entire area of the melting portion. According to the spark plug of this aspect, the joining property between the grounding electrode and the metal shell is secured at a higher level.

[3] In the melting portion of the spark plug according to another aspect of the present invention, in the cross section, the melting depth may be 25% or more of the thickness of the grounding electrode in the central axis direction. According to the spark plug of this aspect, the joining property between the grounding electrode and the metal shell is secured at a higher level.

[4] In a spark plug according to another aspect of the present invention, in the cross section of the melting portion, the melting depth may be 40% or more of the thickness of the grounding electrode in the central axis direction. According to the spark plug of this aspect, the joining property between the grounding electrode and the metal shell is secured at a higher level.

[5] In the melting portion of the spark plug according to another aspect of the present invention, in the cross section, the area of the shell-side portion is 26% or more of the entire area of the melting portion. According to the spark plug of this aspect, the joining property between the grounding electrode and the metal shell is secured at a higher level.

[6] In a spark plug according to another aspect of the present invention, the grounding electrode may include an outer circumferential end portion which comes into contact with the entire inner circumference of the inner wall surface in the through-hole of the metal shell, and the melting portion may be formed on the entire outer circumference side of the outer circumferential end portion. According to the spark plug of this aspect, the joining property of the grounding electrode having the outer circumferential end portion coming into contact with the entire inner circumference of the metal shell with respect to the metal shell is increased.

In a spark plug according to another aspect of the present invention, the grounding electrode includes: an arc shaped outer arc portion which is positioned at an outer circumferential side and faces the inner wall surface of the through-hole; an inner annular portion which surrounds an outer circumference of the tip portion of the center electrode; and a connection portion which is provided between the outer arc portion and the inner annular portion and connects the outer arc portion and the inner annular portion, and the melting portion may be formed at least between a portion of the outer arc portion to which the connection portion is connected, and a wall portion of the metal shell. According to the spark plug of this aspect, the joining property of the grounding electrode having the outer arc portion and the inner annular portion connected by the connection portion with respect to the metal shell is secured.

[8] In a spark plug according to another aspect of the present invention, the connection portion may include a plurality of columnar connection portions radially extending toward the outer arc portion from the inner annular portion, and the melting portion may be formed to correspond to at least each of the plurality of columnar connection portions. According to the spark plug of this aspect, the joining property of the grounding electrode including the outer arc portion and the inner annular portion with respect to the metal shell is secured at a higher level.

The present invention can be realized in various aspects other than the spark plug. For example, the present invention may be realized in aspects such as a manufacturing method or a manufacturing apparatus of the spark plug, a joining method or a joining apparatus of the grounding electrode and the metal shell, a computer program for realizing the methods and apparatuses, and a recording medium which records the computer program and which is not temporary.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic view showing a configuration of a plasma jet ignition plug.

FIG. **2** is a schematic view for explaining an attachment state and an attachment method of a grounding electrode with respect to a metal shell.

FIG. **3** is a schematic view for explaining a process of laser welding of the grounding electrode with respect to the metal shell.

FIG. **4** is a schematic view for explaining a welding position when a melting portion is formed.

FIG. **5** is a schematic view showing a predetermined cutting surface for defining the melting portion.

FIG. **6** is a schematic sectional view for explaining a cross-sectional configuration of the melting portion on the predetermined cutting surface.

FIG. **7** is an explanatory view showing a result of a verification experiment of welding strength between the grounding electrode and the metal shell.

FIG. **8** is an explanatory view showing scattered plots of the test results of the welding strength.

FIG. **9** is a schematic view showing a configuration of a grounding electrode having a spark plug of a second embodiment.

FIG. **10** is an explanatory view showing results of a verification experiment of welding strength between a grounding electrode and a metal shell in a configuration in which the melting portion is not formed over the entire outer circumference of the grounding electrode.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

A. First Embodiment

FIG. **1** is a schematic view showing a configuration of a plasma jet ignition plug **100** (hereinafter, simply referred to as an "ignition plug **100**") according to a first embodiment of the present invention. In FIG. **1**, a central axis CX of the ignition plug **100** is indicated by a dashed line. In the present specification, a direction parallel to the central axis CX is also referred to as a "central axis direction". In FIG. **1**, for convenience, a left side of a paper surface from the central axis CX of the ignition plug **100** is shown by a schematic sectional view, and a right side of the paper surface from the central axis CX is shown by a schematic appearance view.

The ignition plug **100** is attached to a combustion chamber of an internal combustion engine in which diluted mixed gas is used as the fuel gas, and is used for the ignition of the fuel gas. In the ignition plug **100**, a tip side (lower side of the paper surface) is disposed in the combustion chamber, and the rear end side (upper side of the paper surface) is disposed on the outer portion of the combustion chamber. In the ignition plug **100**, plasma is generated in the tip side disposed in the combustion chamber and is injected, and thus, it is possible to secure high ignitability with respect to the fuel gas having a high ignition limit air-fuel ratio.

The ignition plug **100** includes a center electrode **10**, a grounding electrode **20**, an insulator **30**, a terminal electrode **40**, and a metal shell **50**. The center electrode **10** is configured of a shaft-shaped electrode member, and includes a metal core **13**, which is configured of a metal such as copper having excellent thermal conductivity, in the inner portion of the center electrode. The center electrode **10** includes a disk-shaped electrode tip **15**, which is configured of alloy having noble metal, tungsten, or the like as main components, on the tip of the center electrode. The electrode tip **15** is integrated with the center electrode **10** by welding. The electrode tip **15** may be omitted. The center electrode **10** is held in an axial hole **31** of the insulator **30** on the central axis CX. The center electrode **10** is electrically connected to an external power source via the terminal electrode **40** which is held on the rear end side of the axial hole **31** of the insulator **30**.

The grounding electrode **20** is an approximately disk-shaped electrode member having a through-hole **21** in the center thereof. An approximately cylindrical noble metal tip **26** is attached so as to be integrated with the through-hole **21** of the grounding electrode **20**. The noble metal tip **26** may be omitted. The grounding electrode **20** is joined so as to be integrated with the metal shell **50** in a state where the outer circumferential end surface of the grounding electrode comes into contact with the inner wall surface of the metal shell **50**. In the ignition plug **100** of the present embodiment, joining strength (welding strength) of the grounding electrode **20** with respect to the metal shell **50** is secured by laser welding. The details of an attachment state of the grounding electrode **20** with respect to the metal shell **50** or an attachment method will be described below.

The insulator **30** is a shaft-shaped member having an axial hole **31** penetrating the center of the insulator, and, for example, is configured of a ceramic sintered body such as alumina or aluminum nitride. The insulator **30** includes a tip-side portion **33** extending to the tip side, a flange portion **36** positioned at the rear end of the tip-side portion **33**, and a rear end-side portion **37** extending from the flange portion **36** to the rear end side. A stepped surface **35** which is an annular surface facing the tip side is formed in the vicinity of the center portion in the central axis direction of the tip-side portion **33**. The diameter of the tip side of the tip side portion **33** is smaller than that of the rear end side, with the stepped surface **35** as a boundary. The diameter of the flange portion **36** locally becomes larger than diameters of other portions in the rear step side of the stepped surface **35**, and thus, the flange portion **36** is an annular portion which protrudes in a radial direction (a direction perpendicular to the central axis CX) of the insulator **30**. The central axis of the insulator **30** coincides with the central axis CX of the ignition plug **100**. At least the tip-side portion **33** is accommodated in a cylindrical hole **51** of the metal shell **50**. The rear end-side portion **37** extends from the rear end-side opening of the metal shell **50**, and thus, the insulator **30** is held by the metal shell **50**.

As described above, the center electrode **10** is held in the axial hole **31** of the tip-side portion **33** of the insulator **30**. A reduced-diameter opening portion **32** in which the opening diameter of the axial hole **31** is decreased is formed on the tip portion of the insulator **30**. The peripheral edge of the tip surface of the electrode tip **15** positioned at the tip of the center electrode **10** abuts onto the stepped surface of the rear end side of the reduced-diameter opening portion **32** so as to be locked thereto. In the ignition plug **100**, the plasma is formed in an internal space **32***s* of the reduced-diameter opening portion **32** (the details will be described below). Hereinafter, the internal space **32***s* also is referred to as a "cavity **32***s*." The terminal electrode **40** which is a shaft-shaped electrode member is held in the axial hole **31** of the rear end-side portion **37** of the insulator **30**. A resistor **45** is disposed between the center electrode **10** in the axial hole **31** of the insulator **30** and the terminal electrode **40**. A first seal material and a second seal material **46** and **47** are disposed on the tip side and the rear end side of the resistor **45**, respectively. The center electrode **10** and the terminal electrode **40** are electrically connected to each other via the resistor **45** which is interposed between the first glass seal material **46** and the second glass seal material **47**. Accordingly, in the ignition plug **100**, occurrence of radio noise is prevented when spark discharge is generated. In addition, the resistor **45** may be omitted.

The metal shell **50** is an approximately cylindrical member having a cylindrical hole **51** at the center thereof, and configures a housing of the ignition plug **100**. For example, the metal shell **50** is configured of metal such as carbon steel. The central axis of the metal shell **50** coincides with the central axis CX of the ignition plug **100**. The metal shell **50** includes a shell tip-side portion **50***a* which is disposed inside the attachment hole (not shown) of the internal combustion engine, and a shell rear end-side portion **50***b* which is disposed outside the attachment hole.

As described above, the grounding electrode **20** is attached to the tip-side opening end portion **55** of the cylindrical hole **51** in the shell tip-side portion **50***a*. Moreover, the center electrode **10** held by the tip-side portion **33** of the insulator **30** is accommodated in the cylindrical hole **51** of the shell tip-side portion **50***a*. A screw portion **52***s* is formed on the outer circumferential surface of the shell tip-side portion **50***a* and is dimensioned to be screwed to a threaded groove provided on the inner circumferential surface of the attachment hole of the internal combustion engine. A threaded groove is provided in the screw portion **52***s* to fix the ignition plug **100** to the combustion chamber of the internal combustion engine.

The shell rear end-side portion **50***b* includes a crimping portion **54** for fixing the insulator **30** to the opening end portion of the rear end side. The crimping portion **54** is formed to crimp the opening end portion of the rear end side of the shell rear end-side portion **50***b* to the inside in a state where the flange portion **36** of the insulator **30** is accommodated in the cylindrical hole **51** and the stepped surface **35** of the insulator **30** engages with a protrusion **53** of the cylindrical hole **51**. In addition, a talc layer **70** filled with talc powder and ring-shaped wire packings **71** and **72** are disposed between the inner wall surface of the crimping portion **54** and the rear end-side surface of the flange portion **36** of the insulator **30**. Accordingly, air-tightness is secured between the metal shell **50** and the insulator **30**.

In addition, the shell rear end-side portion **50***b* includes a tool engaging portion **56**, a thin portion **57**, and a flange portion **58** in this order from the rear end side. The tool engaging portion **56** has a polygonal cross section protruding in the radial direction, and is formed at a position adjacent to the crimping portion **54**. When the ignition plug **100** is attached to the internal combustion engine, a tool such as a spanner engages with the tool engaging portion **56**. The thin portion **57** is a portion which is positioned between the tool engaging portion **56** and the flange portion **58**. The thin portion **57** is a portion having the thinnest thickness in the metal shell **50**, and when the crimping portion **54** is formed, the thin portion is slightly bent to the outside by the external force applied to the metal shell **50**.

The flange portion **58** is an annular portion protruding in the radial direction (the direction perpendicular to the central axis CX) of the metal shell **50**, and is formed on the tip-side end portion of the shell rear end-side portion **50***b*. The flange portion **58** is disposed outside the combustion chamber when the ignition plug **100** is attached to the internal combustion engine. A ring-shaped gasket **73** is disposed on the tip-side surface of the flange portion **58**. The gasket **73** is pressed by the flange portion **58** when the ignition plug **100** is attached to the internal combustion engine, and is sealed between the combustion engine and the metal shell **50**.

FIG. **2** is a schematic view for explaining the attachment state and the attachment method of the grounding electrode **20** with respect to the metal shell **50**. In the upper portion of the paper surface of FIG. **2**, the front surface side of the grounding electrode **20** when viewed in the central axis direction is shown. In the present specification, the "front surface" in the grounding electrode **20** indicates the surface facing the tip side when the grounding electrode is attached to the ignition plug **100**, and the "rear surface" indicates the surface facing the rear end side. In the lower portion of the paper surface of FIG. **2**, a schematic cross-sectional configuration of the ignition plug **100** after the grounding electrode **20** is joined to the metal shell **50** is shown. In the lower portion of the paper surface of FIG. **2**, the ignition plug **100** is shown in a direction opposite to FIG. **1**, that is, a direction in which the upper side in the paper surface is defined as the tip side and the lower side in the paper surface is defined as the rear end side. In FIG. **2**, the grounding electrode **20** of the upper portion of the paper surface and the grounding electrode **20** of the lower portion of the paper surface are shown so as to correspond to each other.

As described above, the grounding electrode **20** has an approximately disk shape including the through-hole **21** in the center thereof. The grounding electrode **20** is attached to the metal shell **50** in a state where the outer circumferential end surface **22** comes into contact with an inner wall surface **55***s* of the tip-side opening end portion **55** of the metal shell **50**. The outer circumferential edge in the rear surface side of the grounding electrode **20** opposes the stepped surface **52***d* facing the tip side in the cylindrical hole **51** of the metal shell **50**. In addition, the inner circumferential edge around the through-hole **21** in the rear surface side of the grounding electrode **20** opposes the tip surface **34** around the reduced-diameter opening portion **32** of the insulator **30**. The noble metal tip **26** is attached to engage with the inner circumferential wall surface of the through-hole **21** of the grounding electrode **20**. The cavity **32***s* formed on the tip of the insulator **30** communicates with the cylindrical hole **26***c* of the noble metal tip **26** and communicates with the outside via the cylindrical hole **26***c*. That is, it can be regarded that the cavity **32***s* communicates with the outside via the through-hole **21** of the grounding electrode **20**.

The cavity **32***s* is disposed between the electrode tip **15** of the tip portion of the center electrode **10** and the noble metal tip **26** in the through-hole **21** of the grounding electrode **20**. In the ignition plug **100**, a pathway of spark discharge between the center electrode **10** and the grounding electrode **20** is formed in the cavity **32***s*. That is, a spark gap of the ignition plug **100** is surrounded by the insulator **30**. In the ignition plug **100**, when a high voltage is applied to the center electrode **10** via the terminal electrode **40** (FIG. **1**), the spark discharge is generated between the center electrode **10** and the grounding electrode **20**, and plasma is formed in the cavity **32***s* by the spark discharge. The plasma is injected to the tip side via the through-hole **21** (more specifically, the cylindrical hole **26***c* of the noble metal tip **26**) of the grounding electrode **20** from the cavity **32***s*, and thus, ignites the fuel gas in the combustion chamber.

As described below, the grounding electrode **20** is attached to the cylindrical hole **51** in the shell tip-side portion **50***a* of the metal shell **50** and is integrated therewith. The diameter of the grounding electrode **20** is approximately the same as the opening diameter of the tip-side opening end portion **55** of the metal shell **50**. First, the outer circumferential end surface **22** of the grounding electrode **20** and the inner wall surface **55***s* in the tip-side opening end portion **55** of the metal shell **50** come into surface-contact with each other, and the grounding electrode **20** is fitted into the cylindrical hole **51** of the metal shell **50** so that the central axis of the grounding electrode **20** coincides with the central axis CX.

As described above, the annular stepped surface **52***d* facing the tip side is formed in the cylindrical hole **51** of the shell tip-side portion **50***a*. The outer circumferential end portion of the grounding electrode **20** is disposed so as to be locked to the stepped surface **52***d* of the cylindrical hole **51**.

After the grounding electrode **20** is disposed on the stepped surface **52***d* of the shell tip-side portion **50***a*, the grounding electrode is joined to a cylindrical wall portion **52** of the shell tip-side portion **50***a* by laser welding. By the laser welding, the constituent material of the grounding electrode **20** and the constituent material of the metal shell **50** are melted to each other in a portion between the outer circumferential end portion of the grounding electrode **20** and the cylindrical wall portion **52** in the tip-side opening end portion **55** of the shell tip-side portion **50***a*, and thus, a melting portion **5** is formed.

FIG. **3** is a schematic view for explaining the process of the laser welding of the grounding electrode **20** with respect to the metal shell **50**. FIG. **3** shows a schematic cross section of the metal shell **50** at a position cut along line A-A of FIG. **2** in a state where the grounding electrode **20** is fitted to the tip-side opening end portion **55**. In FIG. **3**, a moving locus of a laser emitting portion **200** in the laser welding process is schematically shown. In the laser welding process with respect to the grounding electrode **20**, the laser is emitted from the laser emitting portion **200** of a laser welding machine over the entire outer circumference of the grounding electrode **20** with a predetermined interval in plural times (for example, approximately 80 to 120 times). Accordingly, the plurality of melting portions **5** are formed over the entire outer circumference of the grounding electrode **20** in a state where the melting portions adjacent to each other are connected to each other so as to overlap in the end portions.

FIG. **4** is a schematic view for explaining a welding position when the melting portion **5** is formed. FIG. **4** shows a schematic cross section at the boundary between the grounding electrode **20** and the tip-side opening end portion **55** of the metal shell **50** before the laser welding is performed. In FIG. **4**, a plurality of the laser emitting portions **200** when the laser is emitted at positions different from one another are shown. When the melting portion **5** is formed, the laser emitting portion **200** emits laser to the position at which the melting portion **5** is formed while maintaining a predetermined angle θ which is set in advance with respect to the radial direction (a horizontal direction in the paper surface) of the grounding electrode **20** or the metal shell **50**.

The forming position of the melting portion **5** in the radial direction of the grounding electrode **20** or the metal shell **50** is adjusted by the position of the laser emitting portion **200** in the radial direction. In the present specification, the position of the laser emitting portion **200** in the radial direction when the melting portion **5** is formed is referred to as the "welding position". When the position of the laser emitting portion **200** when laser is emitted to the boundary position between the outer circumferential end surface **22** of the grounding electrode **20** and the inner wall surface **55***s* of the metal shell **50** is defined as a starting point, the welding position is represented by a movement distance of the laser emitting portion **200** with respect to the starting point. Moreover, in the welding position, a direction (a direction toward the outer circumferential side) in which the laser emitting portion **200** approaches the cylindrical wall portion **52** of the tip-side opening end portion **55** is defined as a plus direction, and a direction (a direction toward the inner circumferential direction) away from the cylindrical wall portion **52** is defined as a minus direction.

In the ignition plug **100**, since the grounding electrode **20** is directly exposed to a high combustion pressure in the combustion chamber, preferably, the grounding electrode **20** and the metal shell **50** are joined to each other by higher welding strength. The inventors of the present invention found that the melting portion **5** was formed to have a predetermined melting depth and a predetermined area in a predetermined cutting surface MS described below, and thus, high welding strength was secured between the grounding electrode **20** and the metal shell **50**.

FIG. **5** is a schematic view showing the predetermined cutting surface MS for defining the melting portion **5**. FIG. **5** shows a portion of a schematic cross section of the metal shell **50** after the grounding electrode **20** is joined in the cutting position similar to FIG. **3**. In FIG. **5**, only one arbitrary meting portion **5** among the plurality of melting portions **5** formed over the entire outer circumference of the grounding electrode **20** is shown.

The cutting surface MS (shown by a two-dot chain line) is a surface which is defined by the melting deepest point DP of the melting portion **5** and the central axis (central axis CX) of the metal shell **50**. The "melting deepest point DP of the melting portion **5**" is a portion which is positioned at the rearmost end side in the melting portion **5**. That is, the melting deepest point is a bottom portion in which a penetration depth of the melting portion **5** in the central axis direction becomes the maximum, and is a portion in which a distance in the central axis direction from a virtual plane defined by the tip-side surface of the grounding electrode **20** having the formed melting portion **5** becomes the maximum.

FIG. **6** is a schematic sectional view for explaining the cross-sectional configuration of the melting portion **5** on the predetermined cutting surface (i.e., plane) MS. In the present specification, a percentage ratio of the melting depth MD of the melting portion **5** on the cutting surface MS with respect to a thickness T in the central axis direction of the grounding electrode **20** is referred to as a "melting depth ratio MDD" (the following Expression (1)). Here, the "melting depth MD of the melting portion **5**" is the maximum distance between the melting deepest point DP and a virtual straight line VL (shown by a dashed line) defined by the tip-side surface of the grounding electrode **20** having the formed melting portion **5**.

$$MDD=(MD/T)\times 100 \qquad (1)$$

In addition, in the present specification, a percentage ratio of an area Sm of the metal shell **50** side of the melting portion **5** in the cutting surface MS with respect to the overall area S of the melting portion **5** on the predetermined cutting surface

MS is referred to as a “melting area ratio MSD” (the following Expression (2)). The “area Sm of the metal shell **50** side of the melting portion **5** in the cutting surface MS” is an area of the melting portion **5** which is included in the outer circumferential side (cylindrical wall portion **52** side) from a virtual boundary straight line BL (shown by a two-dot chain line) connecting endpoints EPa and EPb of the inner wall surface **55**s of the metal shell **50** which are positioned at the tip side and the rear end side of the melting portion **5**, in the cutting surface MS.

$$MSD=(Sm/S)\times 100 \tag{2}$$

The melting depth ratio MDD of the melting portion **5** can be adjusted by a laser output when the melting portion **5** is formed. In addition, the melting area ratio MSD is adjusted by the laser output and the welding position when the melting portion **5** is formed.

In the ignition plug **100** of the present embodiment, each melting portion **5** is formed so that the melting depth ratio MDD is 5% or more and the melting area ratio MSD is 10% or more in the cutting surface MS (the following Inequality Expression (3)).

$$MDD\geq 5\% \text{ and } MDS\geq 10\% \tag{3}$$

Accordingly, high welding strength is secured between the grounding electrode **20** and the metal shell **50**.

Here, in each melting portion **5**, more preferably, the melting depth ratio MDD is 15% or more, and the melting area ratio MSD is 20% or more in the predetermined cutting surface MS (the following Inequality Expression (3a)).

$$MDD\geq 15\% \text{ and } MSD\geq 20\% \tag{3a}$$

Alternatively, in each melting portion **5**, preferably, the melting depth ratio MDD is 20% or more, or the melting area ratio MSD is 20% or more in the predetermined cutting surface MS (the following Inequality Expression (3b)).

$$MDD\geq 20\% \text{ or } MSD\geq 20\% \tag{3b}$$

In addition, the melting area ratio MSD in the predetermined cutting surface MS of each melting portion **5** may be 90% or less (MSD≤90%), and preferably, is 80% or less (MSD≤80%). More preferably, the melting area ratio MSD in the predetermined cutting surface MS is 60% or less (MSD≤60%).

In the ignition plug **100** of the present embodiment, the relationship of Inequality Expression (3) may not be satisfied in the cutting surfaces MS of all melting portions **5** formed on the outer circumference of the grounding electrode **20**. Specifically, in the present embodiment, the relationship of Inequality Expression (3) may be satisfied in the cutting surfaces MS of the melting portions having the number exceeding 90% among all melting portions **5**.

FIG. **7** is an explanatory view showing a result of a verification experiment of welding strength between the grounding electrode **20** and the metal shell **50**. In the verification experiment, a test of the welding strength was performed with respect to test pieces (samples S01 to S16) used in the ignition plug **100** of the present embodiment in which the grounding electrode **20** was welded to the metal shell **50** by laser. In each of the samples S01 to S16, each melting portion **5** was formed according to the welding positions and laser outputs indicated by the table of FIG. **7**. Moreover, also in any of the samples S01 to S16, the emission of the laser was performed for 100 times in order to form the melting portion **5** over the entire outer circumference of the grounding electrode **20**.

The melting area ratio MSD, the melting depth MD, and the melting depth ratio MDD of each of the samples S01 to S16 were measured by cutting an arbitrary melting portion **5** according to the cross section corresponding to the predetermined cutting surface M after the test of the welding strength. The test of the welding strength in each of the samples S01 to S16 was performed by applying a load in the central axis direction to the grounding electrode **20** at a crosshead speed of 5 mm/min using a compression tester (load capacity: 50 kN). Moreover, the measured results of the welding strength shown in FIG. **7** are average values of the measured results in which tests are performed for 3 times with respect to each of the samples S01 to S16.

FIG. **8** is an explanatory view showing scattered plots of the test results in the welding strength of each of the samples S01 to S16. In FIG. **8**, the scattered plots of the measured results of the welding strength in each of the samples S01 to S16 are shown in a state where a vertical axis is defined as the melting depth ratio MDD and a horizontal axis is defined as the melting area ratio MSD. In the samples S01 to S08, S10, and S12 to S16 in which the melting depth ratio MDD was 5% or more and the melting area ratio MSD was 10% or more, the welding strength was more than 2900 N. In the samples S01 to S08 and S12 to S16 in which the melting depth ratio MDD was 15% or more and the melting area ratio MSD was 20% or more, the welding strength was more than 3500 N.

Also in the samples S02 to S07 and S12 to S16 in which the melting depth ratio MDD was 20% or more or the melting area ratio MSD was 20% or more, the welding strength of 3900 N or more was secured. In the samples S03 to S05, S08, and S12 to S16 in which the melting area ratio MSD was 26% or more, the welding strength of 3700 N or more was secured. In the samples S02 to S07 and S12 to S16 in which the melting depth ratio MDD was 25% or more, the welding strength of 3900 N or more was secured. In the samples S03 to S05, S07, S08, and S13 to S16 in which the melting area ratio MSD was 26% or more, the welding strength of 3700 N or more was secured. In the samples S03 to S05, S07, and S13 to S16 in which the melting depth ratio MDD was 25% or more or the melting area ratio MSD was 26% or more, the welding strength of 3900 N or more was secured. In the samples S04, S05, S07, and S14 to S16 in which the melting depth ratio MDD was 25% or more or the melting area ratio MSD was 30% or more, the welding strength of 4000 N or more was secured. In the samples S12 to S16 in which the melting depth ratio MDD was 40% or more, the welding strength of 4500 N or more was secured. In the samples S13 to S16 in which the melting depth ratio MDD was 40% or more and the melting area ratio MSD was 26% or more, the welding strength of 4600 N or more was secured.

As described above, according to the ignition plug **100** of the present embodiment, the melting depth ratio MDD or the melting area ratio MSD are appropriately defined in the predetermined cutting surface MS of each of the melting portions **5** formed over the entire outer circumference of the grounding electrode **20**. Accordingly, the welding strength between the grounding electrode **20** and the metal shell **50** is secured.

B. Second Embodiment

In the first embodiment, the configuration in which the melting portions **5** are formed over the entire outer circumference of the grounding electrode **20** having an approximately disk shape is described. On the other hand, hereinafter, a configuration in which the melting portions **5** are formed on a grounding electrode **20**A which does not have an approximately disk shape will be described as a second embodiment of the present invention. In addition, in descriptions below, the same reference numerals are used for the elements common to the first embodiment.

FIG. **9** is a schematic view showing the grounding electrode **20**A included in a spark plug **100**A of the second embodiment of the present invention. FIG. **9** shows a schematic cross section of the metal shell **50** at a position corresponding to the cutting along line A-A of FIG. **2** after the grounding electrode **20**A is joined. In FIG. **9**, the disposition position of the center electrode **10** is shown by a broken line. Moreover, in FIG. **9**, a central axis CY of each columnar connection portion **82** is shown by a dashed line.

The spark plug **100**A of the second embodiment can ignite the fuel gas by the spark discharge generated in the spark gap between the center electrode **10** and the grounding electrode **20**A. The spark plug **100**A of the second embodiment is the same as the configuration of the ignition plug **100** of the first embodiment except that the tip portion of the center electrode **10** extends from the tip portion of the insulator **30** and the configuration of the grounding electrode **20**A is different from that of the grounding electrode **20**. The grounding electrode **20**A of the second embodiment is attached to the tip-side end portion of the metal shell **50** and is integrated with the metal shell **50** so that the center axis of the grounding electrode **20**A coincides with the central axis CX of the spark plug. Hereinafter, the central axis CX of the spark plug will be described as the central axis of the grounding electrode **20**A.

The grounding electrode **20**A includes a central annular portion **80**, three columnar connection portions **82**, and three arc-shaped connection portions **83**. The central annular portion **80** is an approximately annular portion having a through-hole **81** in the center of the central annular portion, and is positioned at the center of the grounding electrode **20**. The central annular portion **80** corresponds to an inner annular portion. In the spark plug of the second embodiment, the tip of the center electrode **10** is positioned at the center in the through-hole **81** in the central annular portion **80** of the grounding electrode **20**A, and a spark gap is formed in the through-hole **81**. Each columnar connection portion **82** radially extends with the outer circumferential end portion of the central annular portion **80** as an initial point, and extends to the tip side while having an inclination angle with respect to the central axis direction. When viewed in the central axis direction, the columnar connection portions **82** are arranged in approximately equal intervals about the central annular portion **80** so that the angles between the central axes CY are approximately equal to one another. The arc-shaped connection portion **83** is provided on the end portion opposite the central axis CX side of each columnar connection portion **82**. Each columnar connection portion **82** is connected to the center portion of the arc-shaped connection portion **83**. Each arc-shaped connection portion **83** extends to be bent in an approximately arc shape in the circumferential shape of the central axis CX. The arc-shaped connection portion **83** corresponds to an outer arc portion.

After the grounding electrode **20**A is disposed in the cylindrical hole **51** of the metal shell **50** so that an outer circumferential arc surface **83***s* of each arc-shaped connection portion **83** comes into surface contact with the inner wall surface **55***s* in the tip-side opening end portion **55** of the metal shell **50**, the grounding electrode **20**A is joined to the cylindrical wall portion **52** in the tip-side opening end portion **55** of the metal shell **50** by laser welding. By the laser welding, the plurality of melting portions **5** are formed at the boundary position between each arc-shaped connection portion **83** and the metal shell **50**. Similar to the first embodiment, the plurality of melting portions **5** are formed in the state where the melting portions adjacent to each other are connected to each other so as to overlap in the end portions. Moreover, similar to the melting portion **5** described in the first embodiment, also in the second embodiment, the melting portion **5** is formed so that the melting depth ratio MDD and the melting area ratio MSD in the predetermined cutting surface MS satisfy the relationship of the above-described Inequality Expression (3).

In the spark plug **100**A of the second embodiment, it can be regarded that the melting portion **5** is formed at the position corresponding to the columnar connection portion **82** of the grounding electrode **20**A. The welding strength between the grounding electrode **20**A and the metal shell **50** is increased as a formation range of the melting portion **5** on the arc-shaped connection portion **83** about each columnar connection portion **82** is increased. The formation range of the melting portion **5** in each arc-shaped connection portion **83** is a range about the central axis CY of the columnar connection portion **82**, preferably, a central angle α is in a range of 36° or more, and more preferably, the central angle α is in a range of 72° or more.

FIG. **10** is an explanatory view showing a result of a verification experiment of welding strength between the grounding electrode **20**A and the metal shell **50** in the spark plug **100**A of the second embodiment. In this verification experiment, as described below, under the same conditions as those described in the first embodiment, the test of the welding strength was performed on test pieces (samples S20 and S21) of the grounding electrode **20**A and the metal shell **50** connected to each other by laser welding. In the table of FIG. **10**, a schematic view showing the configurations of samples S20 and S21, the formation range of the melting portion **5**, an emitting frequency of laser for welding, the melting depth MD (melting depth ratio MDD), the melting area ratio MSD, and the welding strength which is the test result are given.

The samples S20 and S21 are test pieces of the grounding electrode **20**A and the metal shell **50** used in the spark plug **100**A of the second embodiment. In the sample S20, the melting portion **5** was formed over a range about the central axis CY of each of three columnar connection portions **82** and a range in which the central angle α became approximately 36°. In the sample S21, the melting portion **5** was formed over a range about the central axis CY of each of three columnar connection portions **82** and a range in which the central angle α became approximately 72°.

In this verification experiment, regardless that the melting portion **5** was not formed over the entire outer circumference of the grounding electrode **20**, and also in any of samples S20 and S21, the welding strength of 2500 N or more was secured. Particularly, in the sample S21, the welding strength of 3900 N was secured, and the welding strength having the approximately same level as the samples S01 to S08 and S12 to S16 (FIG. **7**) described in the first embodiment in which the melting portions **5** were formed over the entire outer circumference of the grounding electrode **20** was secured. As a result, it is understood that, more preferably, the melting portions **5** are formed within a range in which the melting portions occupy 60% or more of the outer circumference of the grounding electrode **20**A at the positions corresponding to the columnar connection portion **82**.

As described above, even when the melting portions **5** are not formed over the entire outer circumference of the grounding electrode **20**, if the melting depth ratio MDD and the melting area ratio MSD of the melting portion **5** are appropriately defined, it is possible to secure high welding strength between the grounding electrode **20** and the metal shell **50**. In addition, the position or the range within which the melting portion **5** is formed on the outer circumferential edge of the grounding electrode **20** is appropriately defined, and thus, it is possible to improve the welding strength between the grounding electrode **20** and the metal shell **50**.

C. Modification

C1. Modification 1

In the above-described embodiments, the appropriate melting depth ratio MDD and melting area ratio MSD with respect to the melting portion **5** formed between the grounding electrodes **20** and **20**A and the metal shell **50** are described. Meanwhile, the definitions of the melting depth ratio MDD and the melting area ratio MSD in the melting portion **5** described in the above-described embodiments are not limited to the ignition plug **100** and the spark plug **100**A of the above-described embodiments, and may be applied to the melting portion of the spark plug having the grounding electrode which is melt-joined to the inner wall surface of the tubular metal shell.

C2. Modification 2

The grounding electrode **20** of the first embodiment has an approximately disk shape including the through-hole **21** in the center. The grounding electrode **20**A of the second embodiment includes three columnar connection portions **82** extending from the central annular portion **80** and the arc-shaped connection portion **83** connected to each columnar connection portion **82**. Meanwhile, the grounding electrodes **20** and **20**A are not limited to the configurations described in embodiments, and may include other configurations. For example, the grounding electrode **20** may not be a flat disk shape, and the center of the grounding electrode may be thickened. In addition, irregularities may be formed on the surface of the grounding electrode, and a portion of the outer circumferential end thereof may be notched. The grounding electrode **20**A of the second embodiment may not be the configuration including three columnar connection portions **82**. The grounding electrode **20**A may be a configuration including one or two columnar connection portions **82**, and may be a configuration including four or more columnar connection portions **82**. In the grounding electrode **20**A, the columnar connection portions **82** may not be arranged with equal intervals. In the grounding electrode **20**A, the arc-shaped connection portion **83** is completely omitted, and each columnar connection portion **82** may be directly joined to the inner wall surface of the metal shell **50**. In the grounding electrode **20**A, the central annular portion **80** is omitted, and the tip portion of the columnar connection portion **82** opposes the tip surface or the side surface of the center electrode **10**, and the spark gap may be formed. In this way, the configurations of the grounding electrodes **20** and **20**A are not limited to the configurations described in each of the above-described embodiments. In addition, the configuration of the ignition portion, in which the spark gap is formed, also is not limited to the configuration described in each of the above-described embodiments.

C3. Modification 3

In the first embodiment, the melting portion **5** is formed over the entire outer circumference of the grounding electrode **20**. Meanwhile, in the grounding electrode **20** of the first embodiment, like the second embodiment, the melting portion **5** may be formed on the regions which are distributed in plural on the outer circumference of the grounding electrode **20**. The melting portion **5** may be formed on each of two regions different from each other, and may be formed on each of four or more regions different from one another. Preferably, the melting portion **5** is formed on the region of at least 30% or more on the entire circumference of the grounding electrode **20**. In addition, preferably, the melting portion **5** is formed on the region of 60% or more on the entire circumference of the grounding electrode **20**, and more preferably, is formed on the region of 90% or more.

The present invention is not limited to the embodiments, the examples, or the modifications described above including the configurations of the ignition portions or the like including the insulator, the center electrode, and the grounding electrode. The present invention is not limited to the embodiments, the examples, or the modifications described above, and various configurations can be realized within a scope which does not depart from the gist. For example, in order to solve a portion or the whole of the above-described objects or to achieve a portion or the whole of the above-described effects, it is possible to appropriately replace or combine the technical characteristics in the embodiments, the examples, or the modifications corresponding to the technical characteristics of each aspect described in the column of Summary of the Invention. Moreover, if the technical characteristics are not essential in the present specification, the technical characteristics are appropriately omitted.

DESCRIPTION OF REFERENCE NUMERALS AND SIGNS

5: melting portion
10: center electrode
11: tip portion
20: grounding electrode
21: through-hole
22: outer circumferential end surface
26: noble metal tip
26*c*: cylindrical hole
30: insulator
31: axial hole
32: reduced-diameter opening portion
32*s*: cavity
33: tip-side portion
35: stepped surface
36: flange portion
37: rear end-side portion
40: terminal electrode
41: rear end portion
45: resistor
46, **47**: first and second glass seal material
50: metal shell
50*a*: shell tip-side portion
50*b*: shell rear end-side portion
51: cylindrical hole
52: cylindrical wall portion
52*d*: stepped surface
52*s*: screw portion
53: protrusion
54: crimping portion
55: tip-side opening end portion
55*s*: inner wall surface
56: tool engaging portion
57: thin portion
58: flange portion
60: cap portion
61: thin hole

70: talc layer
71, **72**: wire packing
73: gasket
80: central annular portion
81: through-hole
82: columnar connection portion
83: arc-shaped connection portion
83*s*: outer circumferential arc surface
100: ignition plug
100A: spark plug
CX: central axis

Having described the invention, the following is claimed:

1. A spark plug comprising:
a shaft-shaped center electrode;
a tubular insulator, which accommodates at least a rear end-side portion of the center electrode in an inner portion of the insulator;
a grounding electrode, which is disposed while having a gap between a tip portion of the center electrode and the grounding electrode; and
a tubular metal shell including a through-hole in which the insulator is accommodated,
wherein the grounding electrode is fixed to an inner wall surface of the through-hole of the metal shell,
wherein the grounding electrode is fixed to the metal shell via a melting portion in which the grounding electrode and the metal shell are melted to each other, and
wherein, in a cross section including a bottom portion of the melting portion, which is a rearmost end-side portion in the melting portion, and a central axis of the through-hole:
in the melting portion, a melting depth, which is a distance in a central axis direction of the through-hole between the bottom portion of the melting portion and a virtual straight line including an outline of a tip-side surface of the grounding electrode, is 5% or more of a thickness of the grounding electrode in the central axis direction; and
an area of a shell-side portion of the melting portion, which is positioned at an outer circumferential side of the metal shell from a virtual straight line connecting endpoints of the inner wall surface of the metal shell, is 10% or more of an entire area of the melting portion, the endpoints of the inner wall surface of the metal shell being positioned at a tip-side and a rear end-side of the melting portion in the central axis direction.

2. The spark plug according to claim **1**,
wherein, in the cross section of the melting portion:
the melting depth is 15% or more of the thickness of the grounding electrode in the central axis direction; and
the area of the shell-side portion is 20% or more of the entire area of the melting portion.

3. The spark plug according to claim **2**,
wherein, in the cross section of the melting portion, the melting depth is 25% or more of the thickness of the grounding electrode in the central axis direction.

4. The spark plug according to claim **3**,
wherein, in the cross section of the melting portion, the melting depth is 40% or more of the thickness of the grounding electrode in the central axis direction.

5. The spark plug according to claim **3**,
wherein, in the cross section of the melting portion, the area of the shell-side portion is 30% or more of the entire area of the melting portion.

6. The spark plug according to claim **1**,
wherein the grounding electrode includes an outer circumferential end portion, which comes into contact with an entirety of an inner circumference of the inner wall surface in the through-hole of the metal shell, and
wherein the melting portion is formed on an entirety of an outer circumference side of the outer circumferential end portion.

7. The spark plug according to claim **1**,
wherein the grounding electrode includes:
an arc shaped outer arc portion, which is positioned at an outer circumferential side and faces the inner wall surface of the through-hole;
an inner annular portion, which surrounds an outer circumference of the tip portion of the center electrode; and
a connection portion, which is provided between the outer arc portion and the inner annular portion and connects the outer arc portion and the inner annular portion,
wherein the melting portion is formed at least between a portion of the outer arc portion to which the connection portion is connected, and a wall portion of the metal shell.

8. The spark plug according to claim **7**,
wherein the connection portion includes a plurality of columnar connection portions radially extending toward the outer arc portion from the inner annular portion, and
wherein the melting portion is formed to correspond to at least each of the plurality of columnar connection portions.

9. A spark plug comprising:
a shaft-shaped center electrode;
a tubular insulator, which accommodates at least a rear end-side portion of the center electrode in an inner portion of the insulator;
a grounding electrode, which is disposed while having a gap between a tip portion of the center electrode and the grounding electrode; and
a tubular metal shell including a through-hole in which the insulator is accommodated,
wherein the grounding electrode is fixed to an inner wall surface of the through-hole of the metal shell,
wherein the grounding electrode is fixed to the metal shell via a melting portion in which the grounding electrode and the metal shell are melted to each other, and
wherein, in a cross section including a bottom portion of the melting portion, which is a rearmost end-side portion in the melting portion, and a central axis of the through-hole:
in the melting portion, a melting depth, which is a distance in a central axis direction of the through-hole between the bottom portion of the melting portion and a virtual straight line including an outline of a tip-side surface of the grounding electrode, is 5% or more of a thickness of the grounding electrode in the central axis direction; and
an area of a shell-side portion of the melting portion, which is positioned at an outer circumferential side of the metal shell from a virtual straight line connecting endpoints of the inner wall surface of the metal shell, is 10% or more of an entire area of the melting portion, the endpoints of the inner wall surface of the metal shell being positioned at a tip-side and a rear end-side of the melting portion in the central axis direction,
wherein the grounding electrode includes:
an arc shaped outer arc portion, which is positioned at an outer circumferential side and faces the inner wall surface of the through-hole;

an inner annular portion, which surrounds an outer circumference of the tip portion of the center electrode; and

a connection portion, which is provided between the outer arc portion and the inner annular portion and connects the outer arc portion and the inner annular portion, and

wherein the melting portion is formed at least between a portion of the outer arc portion to which the connection portion is connected, and a wall portion of the metal shell.

10. The spark plug according to claim **9**,

wherein the connection portion includes a plurality of columnar connection portions radially extending toward the outer arc portion from the inner annular portion, and

wherein the melting portion is formed to correspond to at least each of the plurality of columnar connection portions.

11. A spark plug comprising:

a shaft-shaped center electrode;

a tubular insulator having an inner portion in which at least a rear end-side portion of the center electrode is positioned;

a grounding electrode positioned such that a gap exists between a tip portion of the center electrode and the grounding electrode; and

a tubular metal shell including a through-hole in which the insulator is positioned,

wherein the grounding electrode is fused to an inner wall surface of the through-hole of the metal shell via a fused portion, and

wherein, in a cross section defined by a bottom portion of the fused portion, which is the rearmost end-side portion in the fused portion, and a central axis of the through-hole:

in the fused portion, a fused depth which is a distance in a central axis direction of the through-hole between the bottom portion of the fused portion and a virtual straight line including an outline of a tip-side surface of the grounding electrode, is 5% or more of a thickness of the grounding electrode in the central axis direction; and

an area of a shell-side portion of the fused portion, which is positioned at an outer circumferential side of the metal shell from a virtual straight line connecting endpoints of the inner wall surface of the metal shell, is 10% or more of an entire area of the fused portion, the endpoints of the inner wall surface of the metal shell being positioned at a tip-side and a rear end-side of the fused portion in the central axis direction.

12. The spark plug according to claim **11**,

wherein the grounding electrode includes:

an arc shaped outer arc portion, which is positioned at an outer circumferential side and faces the inner wall surface of the through-hole;

an inner annular portion, which surrounds an outer circumference of the tip portion of the center electrode; and

a connection portion, which is provided between the outer arc portion and the inner annular portion and connects the outer arc portion and the inner annular portion,

wherein the fused portion is formed at least between a portion of the outer arc portion to which the connection portion is connected, and a wall portion of the metal shell.

13. The spark plug according to claim **12**,

wherein the connection portion includes a plurality of columnar connection portions radially extending toward the outer arc portion from the inner annular portion, and

wherein the fused portion is formed to correspond to at least each of the plurality of columnar connection portions.

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